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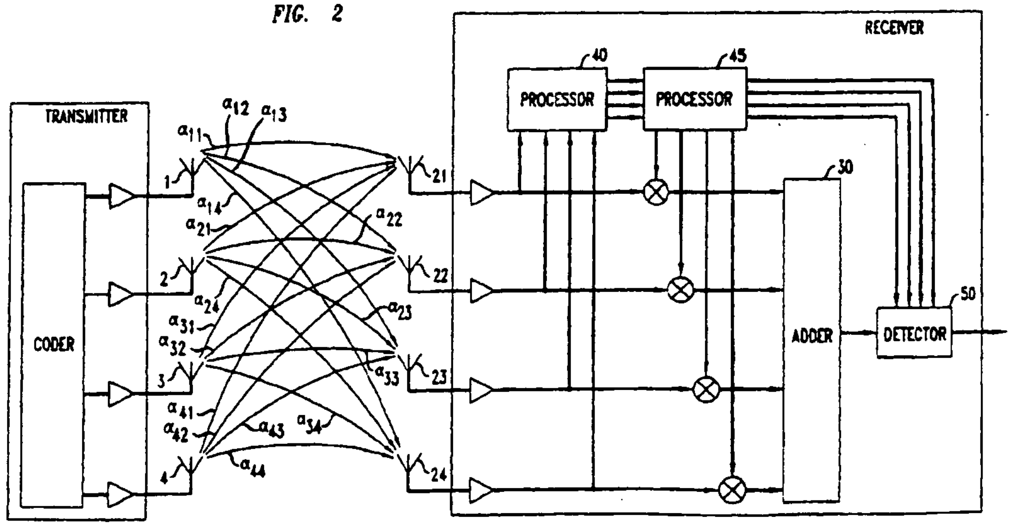
(54) Near-optimal low-complexity decoding of space-time codes for fixed wireless applications

(57) An improved multi-antenna receiver is realized for detecting signals transmitted by a multi-antenna transmitter by summing signals received at the plurality of receiver antennas after multiplying each by a respective constant. The summed signal is applied to a maximum likelihood detector. The respective constants, λ_j, where j is an index designating a particular receiver antenna, are determined by evaluating the largest eigenvalue of the matrix $\Lambda A(\Lambda^*)^T$, where Λ is a vector containing the values λ_j, and A is a matrix containing elements α_{ij}, which is the transfer function between the i^{th} transmitter antenna to the j^{th} receiver antenna. The α_{ij} terms are determined in the receiver in conventional ways.

FIG. 2



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Description

Reference to Related Applications

[0001] This application claims the benefit of U.S. Provisional Application No. 60/068613, filed December 23, 1997.

Background of the Invention

[0002] This invention relates to wireless systems and, more particularly, to systems having more than one antenna at the receiver and at the transmitter.

[0003] Physical constraints as well as narrow bandwidth, co-channel interference, adjacent channel interference, propagation loss and multi-path fading limit the capacity of cellular systems. These are severe impairments, which liken the wireless channel to a narrow pipe that impedes the flow of data. Nevertheless, interest in providing high speed wireless data services is rapidly increasing. Current cellular standards such as IS-136 can only provide data rates up to 9.6 kbps, using 30 kHz narrowband channels. In order to provide wideband services, such as multimedia, video conferencing, simultaneous voice and data, etc., it is desirable to have data rates in the range of 64-144 kbps.

[0004] Transmission schemes for multiple antenna systems may be part of a solution to the problem of the currently available low data rates. Such schemes were first proposed in papers by Wittneben, and by Seshadri and Winters, where the problem was addressed in the context of signal processing.

[0005] One prior art arrangement having a single transmitter antenna and multiple receiver antennas is shown in FIG. 1. Each of the receiver antennas receives the transmitted signal via a slightly different channel, where each channel i is characterized by transfer function α_i. Using an approach known as "Maximum Ratio Combining", the prior art approach to detection contemplates multiplying each received signal that had been influenced by α_i by the complex conjugate signal, α_i^*, summed, and then processed.

[0006] In a co-pending application titled "Method and Apparatus for Data Transmission Using Space-Time Codes and Multiple Transmit Antennas", filed on May 6, 1997, bearing the Serial No. 08/847,635, and assigned to the assignee of this invention, a coding perspective was adopted to propose space-time coding using multiple transmit and receive antennas. Space-time coding integrates channel coding, modulation, and multiple transmit antennas to achieve higher data rates, while simultaneously providing diversity that combats fading. It may be demonstrated that adding channel coding provides significant gains over the schemes of Wittneben and Seshadri and Winters. In said co-pending application, space-time codes were designed for transmission using 2-4 transmit antennas. These codes perform extremely well in slowly varying fading environments (such as indoor transmission media). The codes have user bandwidth efficiencies of up to 4 bits/sec/Hz which are about 3-4 times the efficiency of current systems. Indeed, it can be shown that the designed codes are optimal in terms of the trade-off between diversity advantage, transmission rate, decoding complexity and constellation size.

[0007] It can also be shown that as the number of antennas is increased, the gain increases in a manner that is not unlike a multi-element antenna that is tuned to, say, a particular direction Unfortunately, however, when maximum likelihood detection is employed at the receiver, the decoding complexity increases when the number of transmit and receive antennas is increased. It would be obviously advantageous to allow a slightly sub-optimal detection approach that substantially reduces the receiver's computation burden.

Summary

[0008] Such an approach is achieved with a receiver arrangement where signals received at a plurality of antennas are each multiplied by a respective constant and then summed prior to being applied to a maximum likelihood detector. The respective constants, λ_j, where j is an index designating a particular receiver antenna, are derived from a processor that determines the largest eigenvalue of the matrix $\Lambda A(\Lambda^*)^T$, where Λ is a vector containing the values λ_j, and A is a matrix containing elements α_{ij}, which is the transfer function between the i^{th} transmitter antenna to the j^{th} receiver antenna. The α_{ij} terms are determined in the receiver in conventional ways.

Brief Description of the Drawing

[0009]

FIG. 1 presents a block diagram of Maximal Ratio Combining detection; and

FIG. 2 presents a block diagram of an arrangement including a transmitter having a plurality of antennas, and a receiver having a plurality of antennas coupled to an efficient detection structure.

Detailed Description

[0010] FIG. 1 presents a block diagram of a receiver in accord with the principles of this invention. It includes a transmitter 10 that has an n plurality of transmitting antenna 1, 2, 3, 4, and a receiver 20 that has an m plurality of receiver antennas 21, 22, 23, 24. The signals received by the receiver's antennas are multiplied in elements 25, 26, 27, and 28, and summed in adder 30. More specifically, the received signal of antenna j is multiplied by a value, λ_j, and summed. The collection of factors λ_j can be viewed as a vector Λ. The outputs of the receiver antennas are also applied to processor 40 which, employing conventional techniques, determines the transfer functions α_{ij} for i=1, 2, 3,..., n and j=1, 2, 3,..., m. These transfer functions can be evaluated, for example, through the use of training sequences that are sent by the different transmitter antennas, one antenna at a time.

[0011] The evaluated α_{ij} signals of processor 40 are applied to processor 45 in FIG. 1 where the multiplier signals λ_j,j=1, 2, 3,..., m are computed. Processor 45 also evaluates a set of combined transfer function values γ_i, i=1, 2, 3,..., n (which are described in more detail below). Signals γ_i of processor 45 and the output signal of adder 30 are applied to detector 50 which detects the transmitted symbols in accordance with calculations disclosed below.

[0012] It is assumed that the symbols transmitted by the antennas of transmitter 10 have been encoded in blocks of L time frames, and that fading is constant within a frame. A codeword comprises all of the symbols transmitted within a frame, and it corresponds, therefore, to

$$c_1^1 c_1^2 c_1^3 \ldots c_1^4 c_2^1 c_2^2 c_2^3 \ldots c_2^4 c_3^1 c_3^2 c_3^3 \ldots c_3^4 \ldots c_m^1 c_m^2 c_m^3 \ldots c_m^4,$$

where the superscript designates the transmitter's antennas and the subscript designates the time of transmission (or position within a frame).

[0013] From the standpoint of a single antenna, e.g., antenna 1, the signal that is received at antenna 1 in response to a transmitted symbol c_t^1 at time interval t is:

$$\begin{aligned} R_t &= c_t^1 \left(\alpha_{11}\lambda_1 + \alpha_{12}\lambda_2 + \alpha_{13}\lambda_3 + \ldots + \alpha_{1m}\lambda_m\right) \\ &= c_t^1 \sum_{j=1}^{m} \lambda_j \alpha_{1j} \\ &= c_t^1 \gamma_1 \end{aligned}$$

(when noise is ignored). If each λ_j value is set to α^*_{1j}, (where α^*_{1j} is the complex conjugate of α_{1j}) then the received signal would simply be

$$R_t = c_t^{11} \sum_{i=1}^{m} |\alpha_{11}|^2$$

yielding a constructive addition.

[0014] Of course, the values of λ_j cannot be set to match α^*_{1j} and concurrently to match the values of α^*_{ij} where $i \neq 1$; and therein lies the difficulty.

[0015] When all n of the transmitting antennas are considered, then the received signal is

$$\begin{aligned} R_t &= \sum_{i=1}^{n} \left(c_t^i \sum_{j=1}^{m} \lambda_j \alpha_{ij} \right) \\ &= \sum_{i=1}^{n} c_t^i \gamma_i \end{aligned}$$

[0016] In accordance with the present disclosure, the objective is to maximize

$$\sum_{i=1}^{n} |\gamma_i|^2$$

because by doing so, signal R_t contains as much information about $c_t^i, i = 1,2,3,...n$ as is possible. However, it can be easily shown that if a matrix A is constructed such that

$$A = \sum_{i=1}^{n} (\Omega_i^*)^T \Omega_i,$$

where $\Omega_i = (\alpha_{i1}, \alpha_{12}, \alpha_{13} ... \alpha_{im})$, then

$$\sum_{i=1}^{n} |\gamma_i|^2 = \Lambda A (\Lambda^*)^T.$$

[0017] The receiver, thus, has to maximize $\Lambda A(\Lambda^*)^T$, subject to the constraint $\|\Lambda\|^2 = 1$. The solution to this problem is to choose Λ to be the eigenvector of A which corresponds to the maximum eigenvalue of A. Accordingly, processor 45 develops the matrix A from the values of α_{ij}, finds the eigenvalues of A in a conventional manner, selects the maximum eigenvalue of A, and creates the vector Λ. Once Λ is known, processor 45 develops signals γ_i for 1=1, 2, 3,..., n, (where

$$\gamma_i = \sum_{j=1}^{m} \lambda_j \alpha_{ij}),$$

and applies them to detector 50. Finally, detector 50 minimizes the metric

$$\sum_{t=1}^{L} \left| R_t - \sum_{i=1}^{n} \gamma_i c_t^i \right|^2$$

from amongst all possible codewords in a conventional manner. As can be seen, this approach reduces the complexity of decoding by almost a factor of m.

[0018] FIG. 1 depicts separate multipliers to multiply received signals by multiplication factors λ_i, and it depicts separate blocks for elements 30, 40, 45, and 50. It should be understood, however, that different embodiments are also possible. For example, it is quite conventional to incorporate all of the above-mentioned elements in a single special purpose processor, or in a single stored program controlled processor (or a small number of processors). Other modifications and improvements may also be incorporated, without departing from the spirit and scope of the invention, which is defined in the following claims.

[0019] Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing the intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the scope of each element identified by way of example by such reference signs.

Claims

1. A receiver comprising:

   an n plurality of antennas, where n is greater than one;
   circuitry for obtaining n signals transmitted from m antennas of a transmitter, where m is greater than one; and
   processing means for

      developing a sum signal that corresponds to the addition of said n signals that are each pre-multiplied by a respective factor λ_j, where i is an index integer specifying that factor λ_j multiplies the signal received from

antenna i of said n plurality of antennas,
developing values for transfer functions α_{ij}, where i is an index that references said transmitting antennas, and j is an index that references said receiving antennas,
developing said λ_j factors from said transfer functions, and
detecting symbols transmitted by said m transmitter antennas embedded in said sum signal.

2. The receiver of claim 1 where said factors λ_j are related to said transfer functions α_{ij}.

3. The receiver of claim 1 where said factors are components of a vector Λ where Λ is an eigenvalue of $\Lambda A(\Lambda^*)^T$, and where A is a matrix containing said elements α_{ij}.

4. The receiver of claim 1 where said detecting compares said sum signal to a signal corresponding to symbols c^i possibly transmitted by transmitting antenna i of said m transmitting antennas multiplied by corresponding factors γ_i.

5. The receiver of claim 4 where said corresponding factor γ_i is related to said factors λ_j, for j=1,2, 3, ..., m, and to α_{ij}.

6. The receiver of claim 4 where said detecting maximizes the metric

$$\sum_{t=1}^{L}\left|R_t - \sum_{i=1}^{n} \gamma_i c_t^i\right|^2,$$

where R_t is said sum signal at time interval t within a frame having L time intervals, and c_t^i is the symbol that might have been transmitted over transmitting antenna i at time interval t.

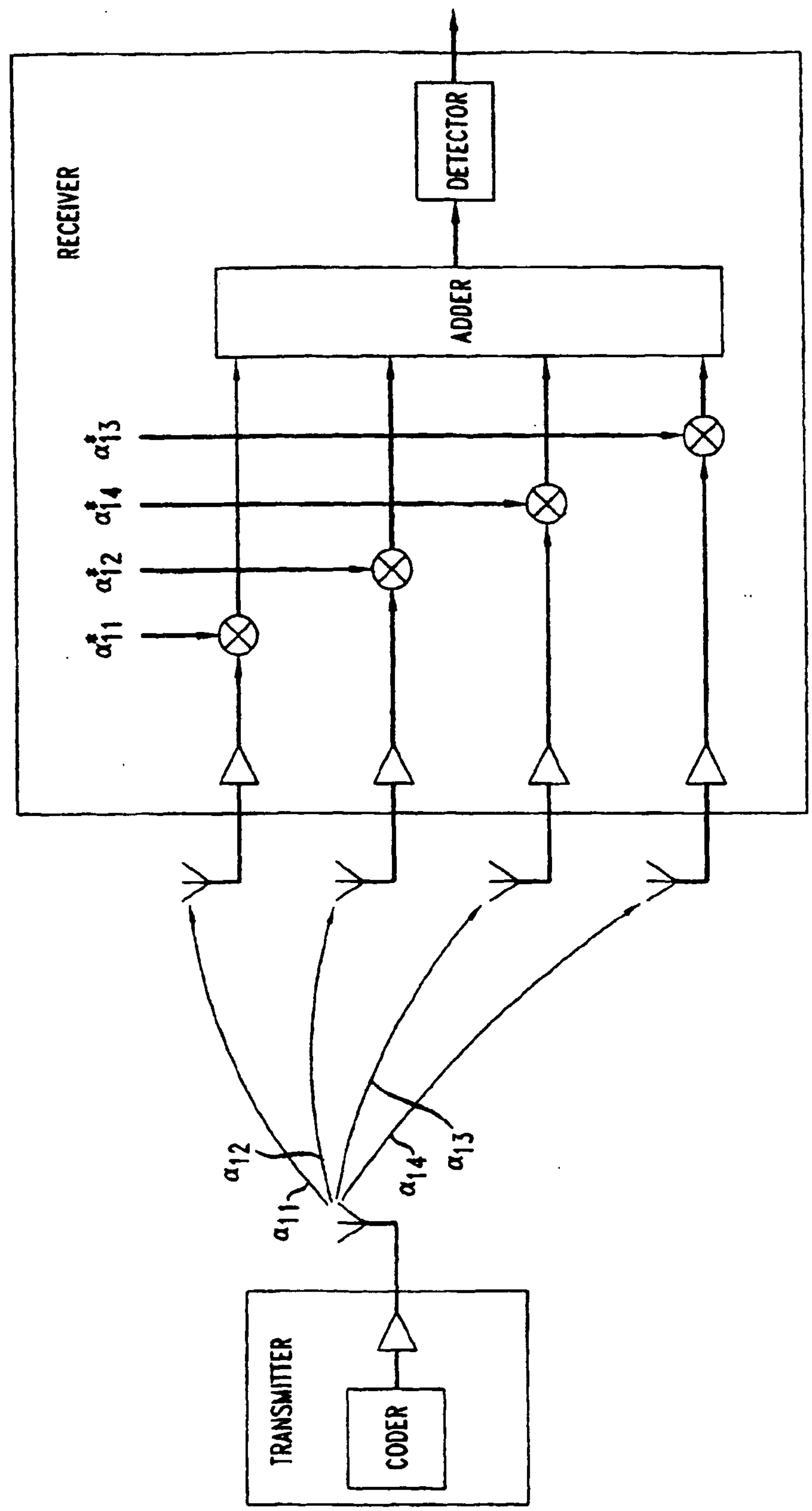
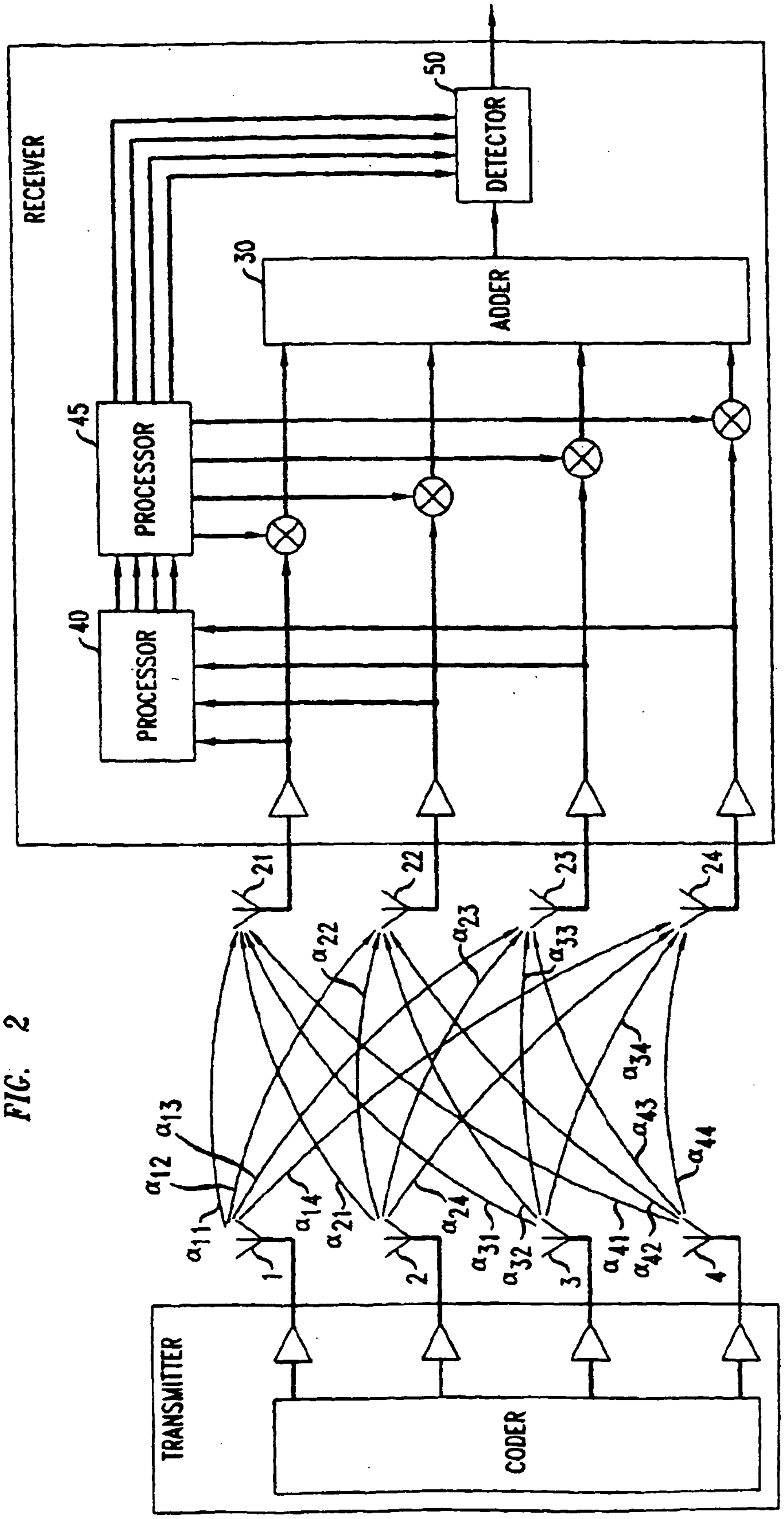


FIG. 1 (Prior Art)

FIG. 2


RECEIVER
DETECTOR
50
ADDER
30
PROCESSOR
45
PROCESSOR
40
21
22
23
24
TRANSMITTER
CODER
1
2
3
4
α_{11}
α_{12}
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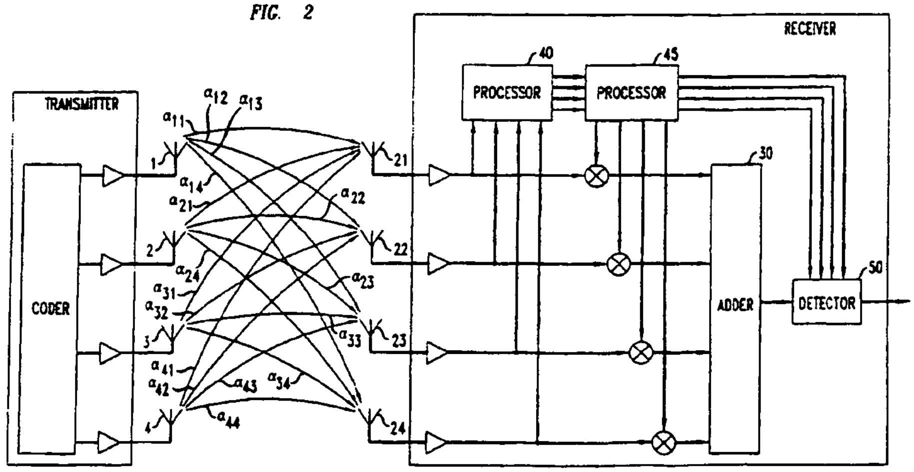

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EUROPEAN SEARCH REPORT

Application Number
EP 98 12 4231

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TECHNICAL FIELDS SEARCHED (Int.Cl.6)

H04L
H04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	23 March 2000	Farese, L

CATEGORY OF CITED DOCUMENTS

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